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(54) **PROVIDING A LOW PHASE NOISE REFERENCE SIGNAL**

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(60) Provisional application No. 60/722,472, filed on Sep. 30, 2005.

(51) **Int. Cl.**
H03K 12/00 (2006.01)

(52) **U.S. Cl.** **327/184**

(58) **Field of Classification Search** None
See application file for complete search history.

(56) **References Cited**

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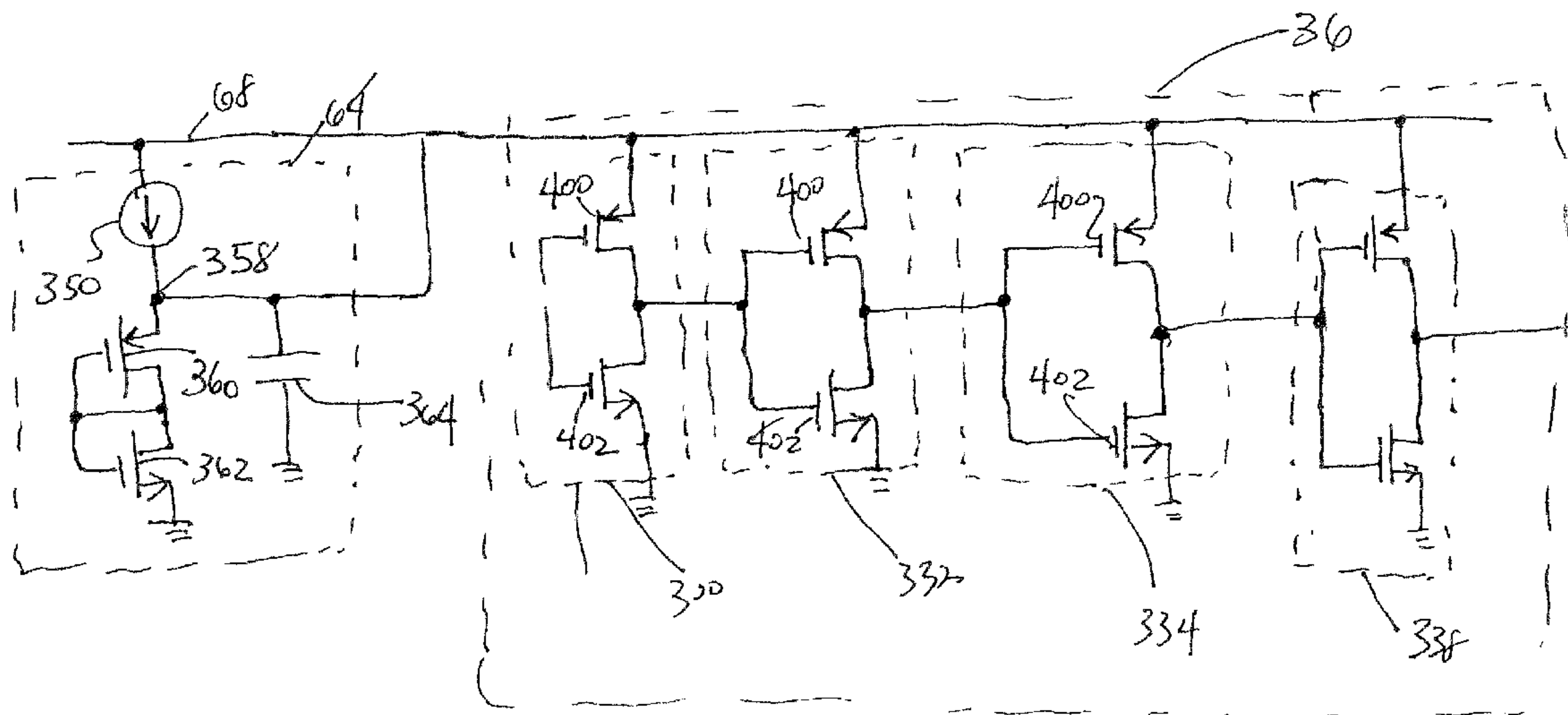
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(57) **ABSTRACT**

A reference clock generator includes an oscillator to generate a periodic signal, a shaping circuit and a filter. The shaping circuit shapes the periodic signal to generate a clock signal. The filter is located between the oscillator and the shaping circuit.

6 Claims, 5 Drawing Sheets



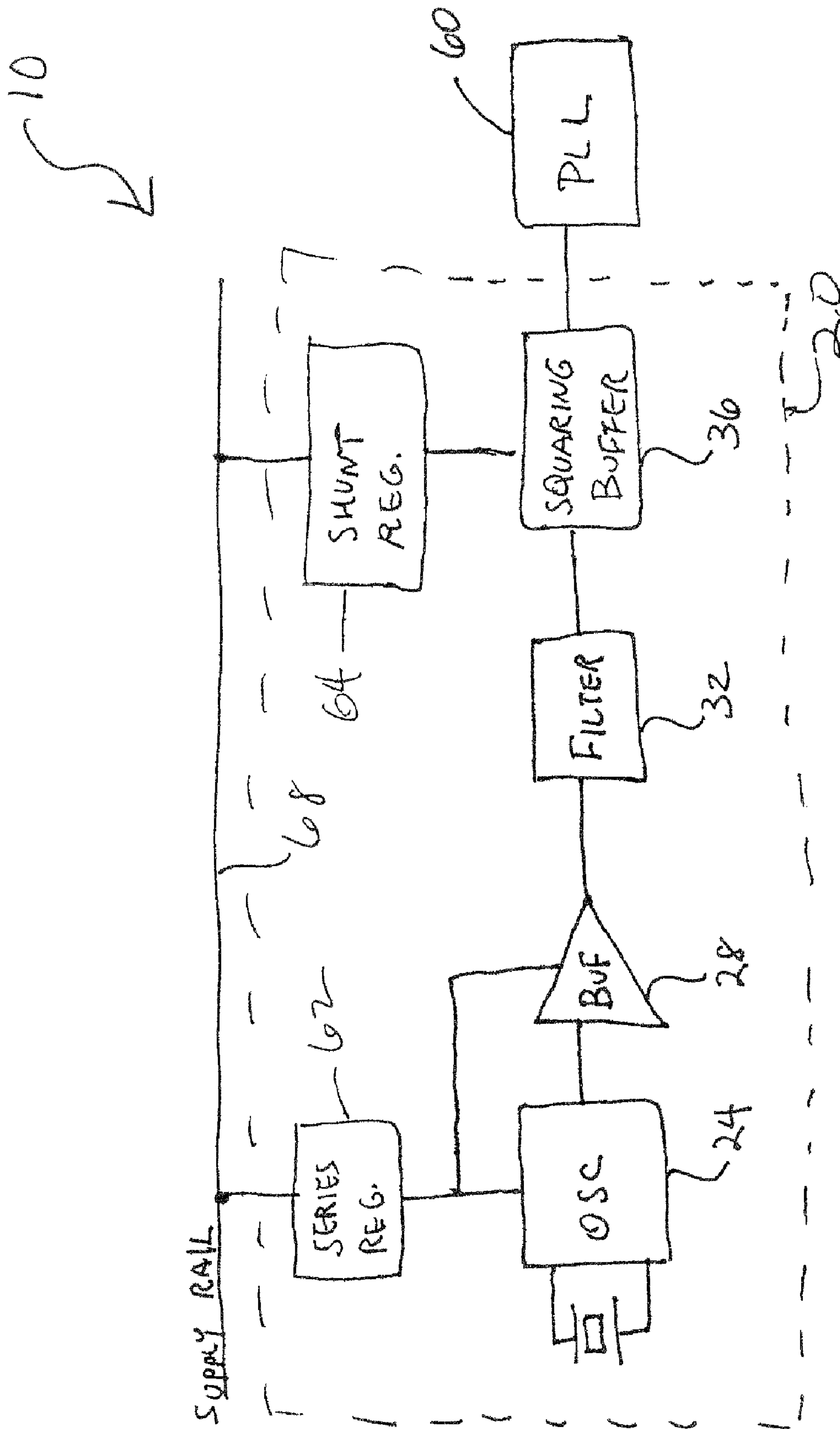


FIG. 1

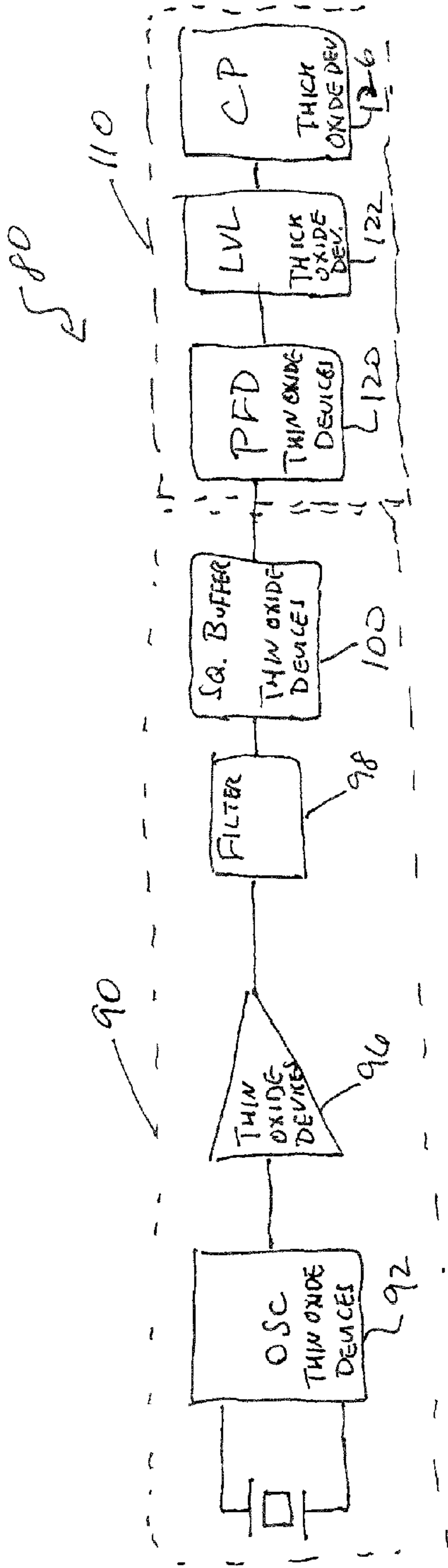


FIG. 2

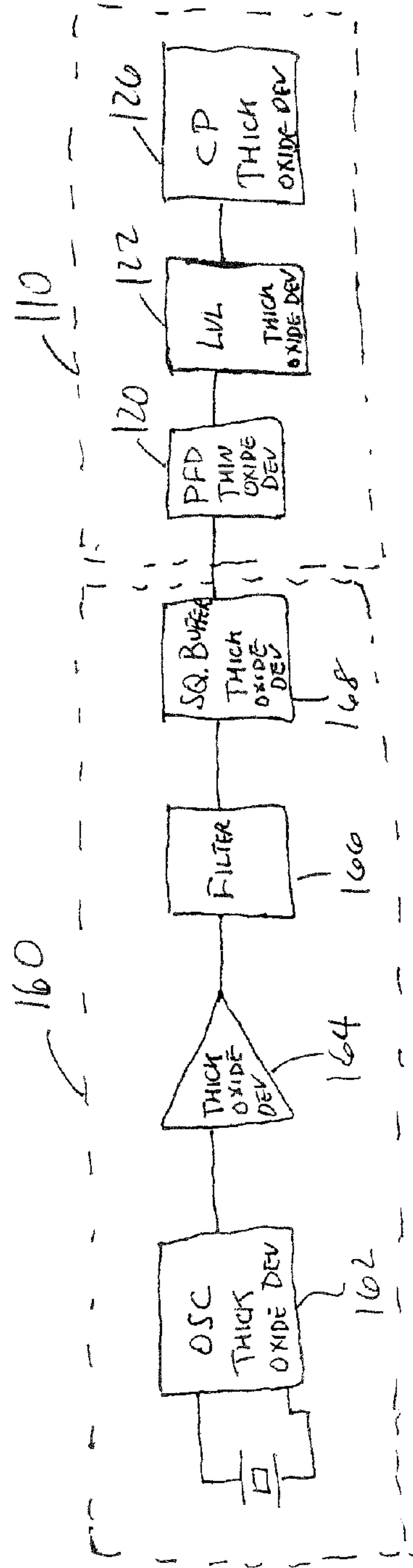


FIG. 3

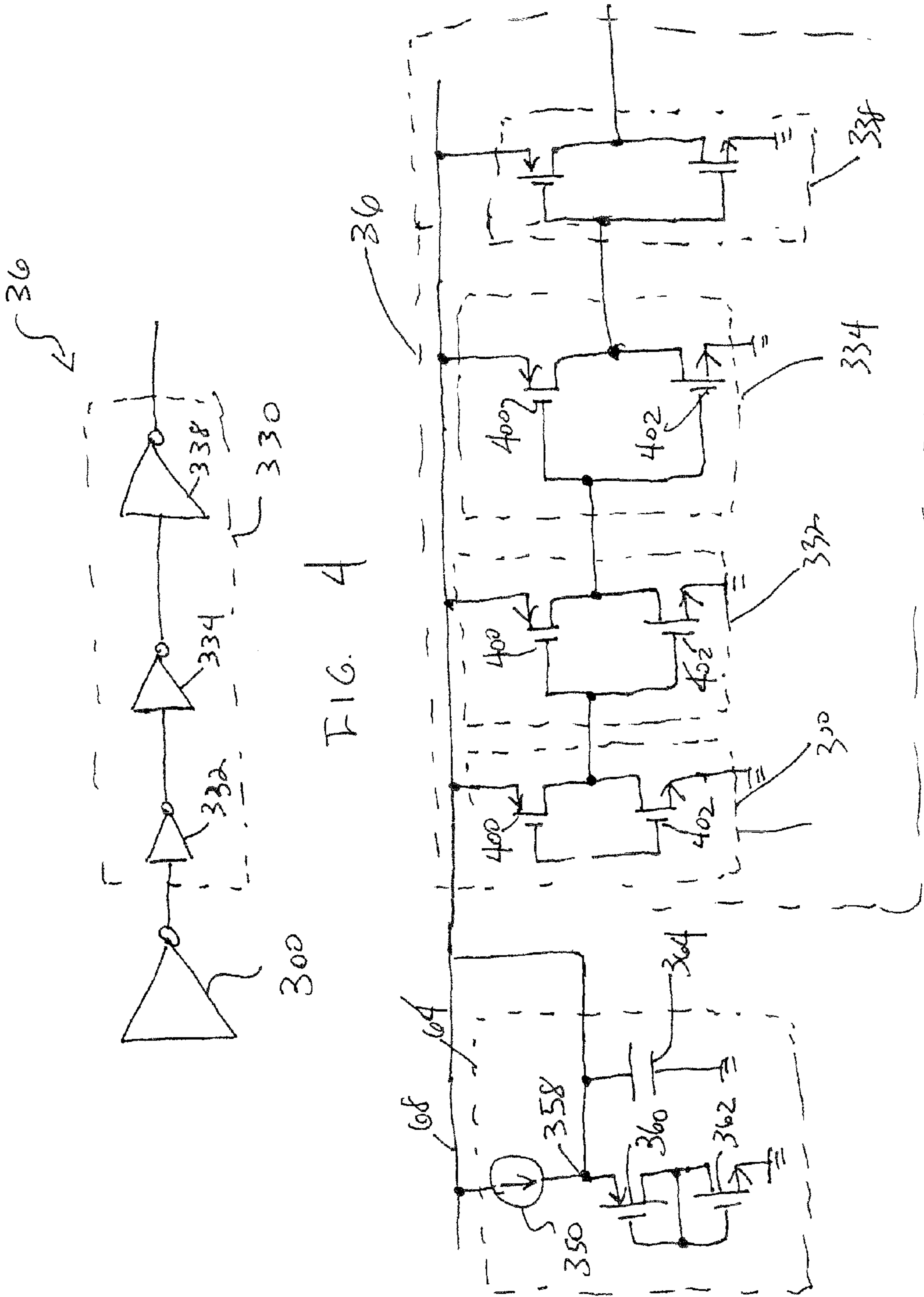


FIG. 4

FIG. 5

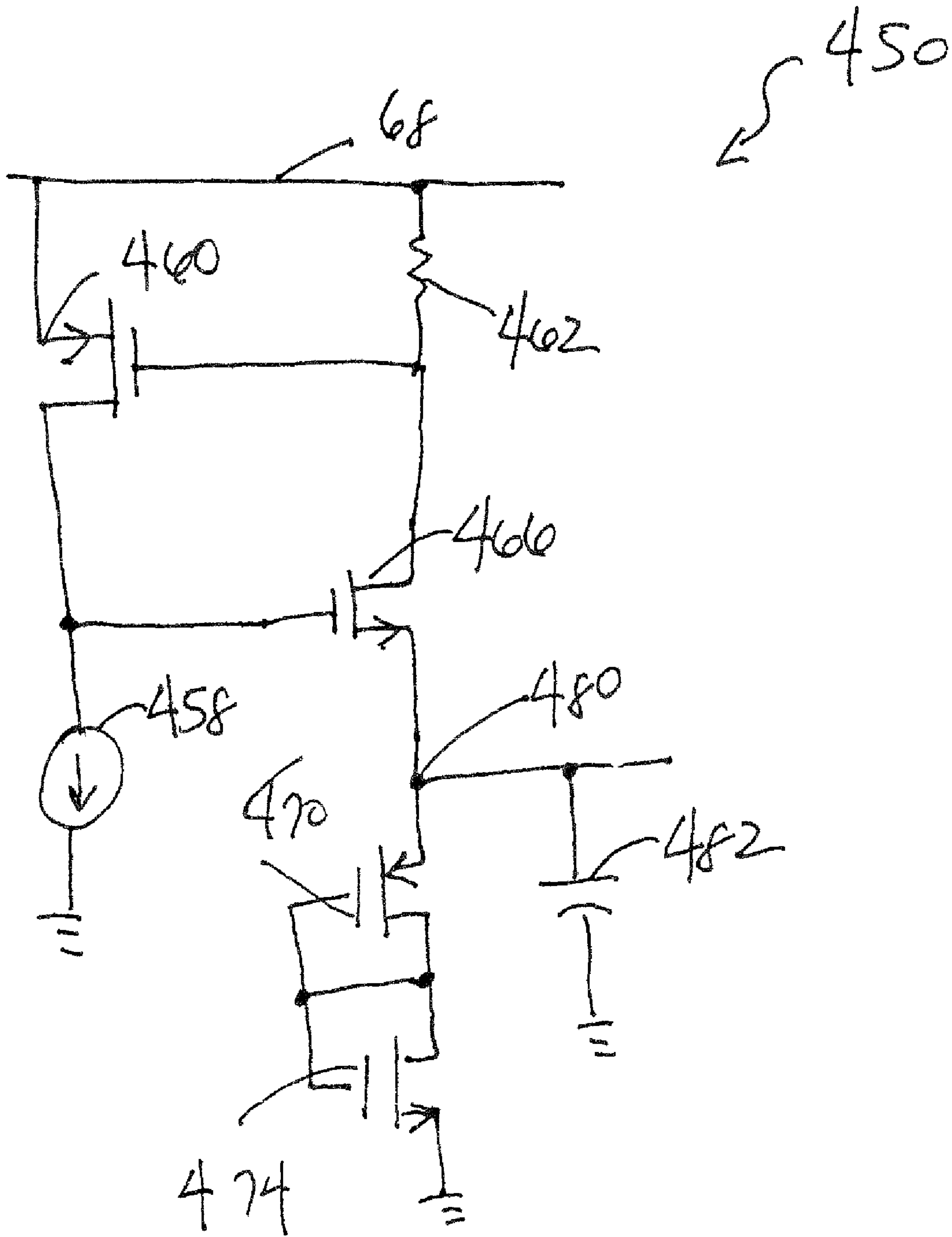


FIG. 6

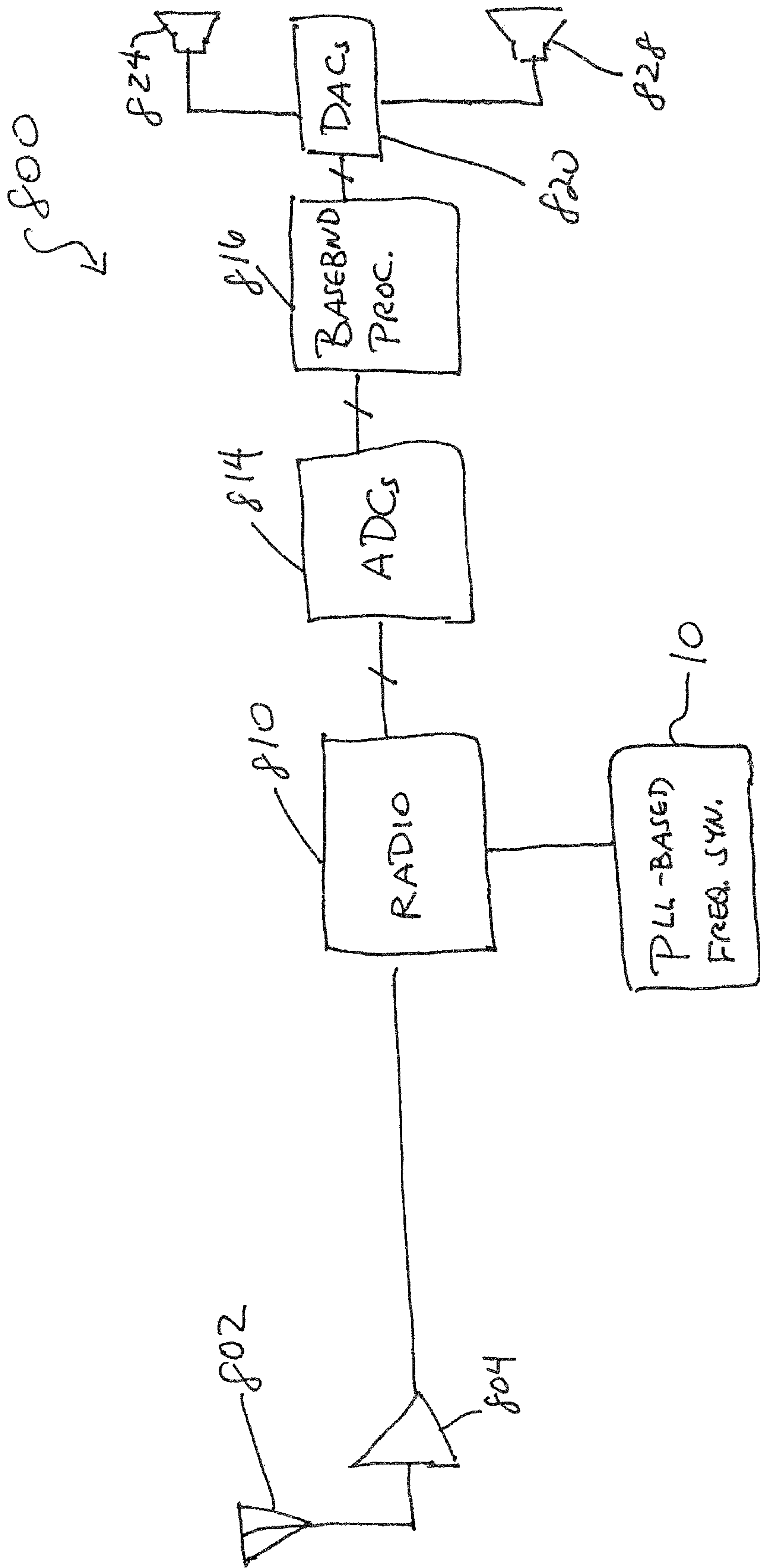


FIG. 7

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**PROVIDING A LOW PHASE NOISE
REFERENCE SIGNAL**

This application is a divisional of U.S. patent application Ser. No. 11/473,742, entitled "PROVIDING A LOW PHASE NOISE REFERENCE CLOCK SIGNAL," filed on Jun. 23, 2006 now abandoned, which claims the benefit under 35 U.S.C. §119(e) to U.S. Provisional Application No. 60/722,472, filed on Sep. 30, 2005. Each of these applications is hereby incorporated by reference in its entirety.

BACKGROUND

The invention generally relates to providing a low phase noise reference clock signal, such as a reference clock signal for a phase locked loop, for example.

A modern communication system typically includes a tunable frequency synthesizer for purposes of generating mixing signals for the system. The frequency synthesizer typically includes a phase locked loop (PLL) and a reference clock generator that provides a reference clock signal to the PLL. The PLL generates the output signal for the synthesizer; and the frequency of the output signal typically is a multiple of the frequency of the reference clock signal. The frequency ratio typically is established by a programmable feedback divider of the PLL.

Modern wideband communications systems have frequency synthesizers that can be tuned over a very wide range at multi-GHz frequencies. It may be desirable for the PLL to have a relatively large bandwidth for purposes of rejecting phase noise that is generated by the controlled oscillator of the PLL. However, a large loop bandwidth may cause the reference clock signal to significantly contribute to the phase noise (i.e., the clock jitter) in the output signal of the synthesizer. The large ratio between the output clock frequency (in the GHz range, for example) and the reference clock frequency (in a tens of MHz range, for example) typically results in a large feedback divider modulus for the PLL and thus, a large gain for the phase noise and the spurious tones that exist in the reference clock path.

Thus, there exists a continuing need for a frequency synthesizer that has a reference clock signal path that introduces an insignificant amount of phase noise and spurious tones to the reference clock signal.

SUMMARY

In an embodiment of the invention, a reference clock generator includes an oscillator to generate a periodic signal, a shaping circuit and a filter. The shaping circuit shapes the periodic signal to generate a clock signal. The filter is located between the oscillator and the shaping circuit.

In another embodiment of the invention, a shaping circuit includes a first inverter to receive a sinusoidal signal and a chain of serially coupled inverters. The chain has an input terminal to receive the sinusoidal signal and an output terminal. The sizes of the inverters progressively increase from the input terminal to the output terminal.

In another embodiment of the invention, a frequency synthesizer includes a clock generator to generate a reference clock signal and a phase locked loop to lock onto the reference signal to generate an output signal. The clock generator includes an oscillator that has first transistors. Each of the first transistors have substantially a first gate oxide thickness. The phase locked loop includes a charge pump that has second transistors. Each of the second transistors has substantially a second gate oxide thickness that is substantially greater than the first gate oxide thickness.

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In yet another embodiment of the invention, a frequency synthesizer includes a clock generator to generate a reference clock signal and a phase locked loop to lock onto the reference clock signal to generate an output signal. The clock generator includes an oscillator that has first transistors, and each of the first transistors has substantially a first gate oxide thickness. The phase locked loop includes a phase detector that has second transistors. Each of the second transistors has substantially a second gate oxide thickness that is substantially smaller than the first gate oxide thickness.

Advantages and other features of the invention will become apparent from the following drawing, description and claims.

BRIEF DESCRIPTION OF THE DRAWING

FIGS. 1, 2 and 3 are schematic diagrams of frequency synthesizers according to embodiments of the invention.

FIG. 4 is a schematic diagram of a squaring buffer according to an embodiment of the invention.

FIG. 5 is a more detailed schematic diagram of the squaring buffer according to an embodiment of the invention.

FIG. 6 is a schematic diagram of an alternative closed-loop shunt regulator for use with the squaring buffer according to an embodiment of the invention.

FIG. 7 is a schematic diagram of a wireless system according to an embodiment of the invention.

DETAILED DESCRIPTION

Referring to FIG. 1, an embodiment of a frequency synthesizer 10 in accordance with the invention includes a phase locked loop (PLL) 60 and a reference clock generator 20 that provides a reference clock signal to the PLL 60. The PLL 60, once locked onto the reference clock signal, provides an output signal that has a predetermined phase and frequency relationship to the reference clock signal. The PLL 60 has a relatively high bandwidth, which makes the PLL 60 potentially susceptible to phase noise and spurious tone contamination in the reference clock signal. However, as described below, the reference clock generator 20 has features that produce a reference clock signal that has relatively low phase noise and an insignificant level of spurious tone contamination.

It is noted that although a single PLL 60 is depicted in FIG. 1, in other embodiments of the invention, the frequency synthesizer 10 may generate multiple output signals having different frequencies and thus, may include multiple PLLs that receive the reference clock signal from the reference clock generator 20.

In accordance with some embodiments of the invention, the reference clock generator 20 includes a crystal reference oscillator 24 that generates a reference sinusoidal signal at its output terminal. The sinusoidal signal, in turn, propagates through an isolation buffer 28 and a filter 32 before reaching a squaring buffer 36. The squaring buffer 36, in turn, reshapes the received sinusoidal signal to form the reference clock signal that is provided to the PLL 60.

More specifically, the squaring buffer 36 performs a non-linear edge squaring operation that effectively corresponds to a phase sampling operation that is capable of upconverting and downconverting phase noise and spurs that are parasitically coupled to the main signal path that carries the main sinusoidal signal. Therefore, the squaring buffer 36 is capable of producing noise and spurs in a band near the carrier frequency of the signal that is produced by the PLL 60, which means the PLL 60 may be incapable of filtering out these tones and spurs. However, the filter 32 is used to filter out

noise and spurs from the signal that is provided to the squaring buffer **32** for purposes of preventing the up and down conversion of the noise and spurs, in accordance with some embodiments of the invention.

As a more specific example, in accordance with some embodiments of the invention, the filter **32** may be a relatively low order passive filter that may be formed, for example, from a resistor-capacitor (R-C) network. It is noted that in accordance with some embodiments of the invention, the reference clock generator **20** may include one or more additional higher order filters for purposes of increasing the effectiveness of the high frequency noise and spur rejection.

The isolation buffer **28**, in accordance with some embodiments of the invention, represents another measure that is used to prevent noise and spurs from propagating from the reference clock generator **20**. The isolation buffer **28** is used to drive the long reference clock lines (that present a high parasitic capacitance) without significantly loading the reference oscillator **24**. More specifically, if a square wave-looking reference clock signal is transmitted over a relatively long signal path between the oscillator **24** and the squaring buffer **36**, the resultant long metal wire connection may radiate a considerable amount of reference clock harmonics, which may be coupled into other sensitive analog blocks of a system that incorporates the frequency synthesizer **10**. The long distance may be especially true for the case in which the clock generator **20** supplies a reference clock signal to several PLLs **60** that are distributed in a particular integrated circuit. Therefore, it is preferred to drive long wires with sinusoidal-looking signals and convert these signals locally into square wave clock signals for local blocks.

In a large mixed signal analog and digital integrated circuit, the supply lines may be contaminated with spurious tones and noise. The noise and spurious tones on the supply lines may be due to, as examples, several PLLs or frequency synthesizers existing on the same integrated circuit; other integrated circuits operating on the same printed circuit board (PCB); and/or various PLL blocks.

The components of the frequency synthesizer **10** ultimately receive their power from a voltage supply rail **68**. However, different regulators are used to directly power the components of the frequency synthesizer **10** for purposes of preventing noise from contaminating the reference clock path and for purposes of preventing noise that is generated by the reference clock generator **20** from propagating outside of the generator **20**.

More specifically, as depicted in FIG. 1, in accordance with some embodiments of the invention, the oscillator **24** and the isolation buffer **28** are not connected directly to the supply rail **68**; but rather, the oscillator **24** and the isolation buffer **28** receive their supply voltages from a series regulator **62** that, in turn, is connected to the supply rail **68**. The series regulator **62** provides a relatively high forward power supply rejection ratio (PSRR), which means the regulator **62** significantly attenuates spurious tones from the supply rail **68** from propagating or being coupled into the reference clock path before the non-linear squaring operation by the squaring buffer **36**. The series regulator **62** needs to have very low output noise performance in order to limit phase noise degradation of the clock signal. The noise (white, colored or 1/f noise), if present, may dominate the noise that is propagates through the squaring buffer **36** and thus, may be up or down converted to a frequency near the carrier frequency of the PLL **60** by the squaring buffer **36**.

Unlike the power supply connections for the oscillator **24** and the buffer **28**, in accordance with some embodiments of the invention, the squaring buffer **36** receives its input power

through a shunt regulator **64**. Thus, the shunt regulator **64** is connected to the supply rail **68** and provides a supply voltage to the squaring buffer **36**. The shunt regulator **64** has a high forward PSRR, and unlike the series regulator **62**, also has a high reverse PSRR. The forward isolation minimizes the amount of spurious tones that are present, which may be down-converted around the reference clock carrier and then amplified by the PLL **60** forward gain. The high reverse PSRR means that the shunt regulator **64** significantly attenuates any noise contamination to the supply rail **68** (and thus, to the global integrated circuit supply lines) by the harmonics of the reference clock signal, which may coupled into other sensitive analog blocks that are coupled to the supply rail **68**.

In accordance with some embodiments of the invention, the gate thicknesses of the complementary metal oxide semiconductor (CMOS) devices that form the frequency synthesizer **10** may be selected for purposes of minimizing noise and spurious tones in the reference clock path. For example, referring to FIG. 2, in accordance with some embodiments of the invention, a frequency synthesizer **80** uses relatively low amplitude signals and in general uses thin oxide devices for purposes of minimizing noise and spurious tones in the reference clock path.

More specifically, similar to the overall topology of the clock generator **20** (FIG. 1), a clock generator **90** of the frequency synthesizer **80** includes a crystal-based oscillator **92**, an isolation buffer **96**, a filter **98** and a squaring buffer **100**. The crystal oscillator **92** uses thin oxide devices for their lower 1/f noise and also uses relatively lower bias currents for a given transconductance level. Similarly, the buffer **96**, if used, includes relatively thin oxide devices. The filter **98** may be a passive filter (as an example) and thus, may not contain any CMOS devices. The squaring buffer **100** also contains thin oxide devices.

The use of the thin oxide devices may continue with the devices of a PLL **110** of the frequency synthesizer **80**. More specifically, a phase detector **120** of the PLL **110** may have relatively thin oxide devices to ensure a minimum width up/down reset pulse, which provides dead-zone-free operation. The PLL **110** also includes a charge pump **126** that uses relatively thick oxide devices to allow a wide oscillator control voltage range which ensures a low gain of the VCO (not shown) of the PLL **110** in light of a low upconversion gain. As also depicted in FIG. 2, the PLL **110** may include level shifters **122** that have relatively thick oxide devices **122**. The noise contribution of the level shifters is negligible due to the fast clock edge rates at their input.

In accordance with other embodiments of the invention, a frequency synthesizer **150** that is constructed to use higher signal magnitudes than the frequency synthesizer **80** may use the PLL **110** with another reference clock generator **160**. Similar to the overall topologies of the clock generators **90** and **20**, the reference clock generator **160** includes a crystal-based oscillator **162**, an isolation buffer **164**, a filter **166** and a squaring buffer **168**. Unlike the reference clock generator **90**, the reference clock generator **160** generally uses thick oxide devices and operates using relatively larger magnitude signals in the reference clock path. Therefore, the crystal-based oscillator **162** and the isolation buffer **164** use the thick oxide devices. Due to its thick oxide devices, the squaring buffer **168** may handle a relatively large amplitude sinusoidal signal that is generated by the oscillator **162**. The large magnitude signals generally reduce the degree of phase noise in the reference clock signal.

Referring to FIG. 4, in accordance with some embodiments of the invention, the squaring buffer **36** is formed from a chain of CMOS inverters. In order for the squaring buffer **36** to be

effective, the buffer **36** needs to boost the rate (called the “edge speed” herein) at which the positive and negative going edges of the received signal change. To accomplish this, the squaring buffer **100** boosts the edge speed starting with a first inverter **300** of the squaring buffer **36**.

In general, the faster the edge speed, the lower the sensitivity to the supply noise and also the device intrinsic noise. If a gradual scaling up of the edge speed is realized along the inverter chain, then each inverter of the chain contributes significant noise to the reference clock signal. Therefore, instead of such an approach, the first inverter **300** of the chain is made sufficiently strong to speed up the edges of the received sinusoidal signal so that the following inverter stages **332**, **334** and **338** have negligible impacts on the reference path noise.

In the context of this application, a “strong” or “large” inverter means an inverter that has relatively larger complementary metal oxide (CMOS) devices than another inverter. In other words, the n-channel metal-oxide-semiconductor field effect transistor (NMOSFET) and p-channel metal-oxide-semiconductor field effect transistor (PMOSFET) devices of a “strong” CMOS inverter have significantly larger aspect ratios than the NMOSFET and PMOSFET devices of a “weak” inverter.

To ensure a very fast speed on the load of the output of the first inverter **300**, the load present on the output terminal of the first inverter **300** is minimized. Therefore, the size of the second inverter **332** of the chain is made significantly smaller than the size of the first inverter **300**. The third inverter **334** is made larger than the second inverter **332**, and the fourth inverter **338** is made larger than the third inverter **334**. Thus, after the first inverter **300**, the sizes of the inverters **332**, **334** and **338** monotonically increase in size, thereby using a graduated approach to gradually and monotonically increase the drive capability. The fourth inverter **338** has a sufficient size to provide the reference clock signal to the PLL.

After the edges are fast enough, minimal gain is necessary to keep the edges squared. Therefore, after the edges are squared by the first inverter **300**, the remaining inverter chain are mainly used for purposes of maintaining a large bandwidth for the squaring buffer **36**.

Referring to FIG. 5, in accordance with some embodiments of the invention, the shunt regulator **64** may be an open loop shunt regulator that includes a current source **350** that is coupled to the supply rail **68** to provide a bias current to an output terminal node **358** of the regulator **64**. Two diodes that are formed from a PMOSFET **360** and an NMOSFET **362** are serially coupled between the node **358** and ground to establish the voltage level of the output terminal node **358**. Thus, the drain and gate terminals of the PMOSFET **360** and the NMOSFET **362** are coupled together. As also depicted in FIG. 5, a filtering capacitor **364** may be coupled between the output terminal node **358** and ground.

As shown in FIG. 5, in accordance with some embodiments of the invention, each of the inverters **332**, **334** and **338** may be a complimentary metal oxide semiconductor (CMOS) inverter that is formed from a PMOSFET **400** and an NMOSFET **402**. The source terminal of the NMOSFET **402** is coupled to ground; the gate terminals of the NMOSFET **402** and the PMOSFET **400** are coupled together to receive an input signal; the drain terminals of the PMOSFET **400** and the NMOSFET **402** are coupled together to form an output terminal for the inverter; and the source of the PMOSFET **400** is coupled to the output node **358**.

Alternatively, referring to FIG. 6, in accordance with some embodiments of the invention, the open-loop shunt regulator may be replaced by a closed loop shunt regulator **450** in

accordance with some embodiments of the invention. The shunt regulator **450** includes two CMOS diodes formed from a PMOSFET **470** and an NMOSFET **474** that are serially coupled between an output node **480** and ground. Thus, in general, the voltage drop across the CMOS diodes provides the regulated output voltage for the regulator **450**. Additionally, a capacitor **482** is coupled between the output node **480** and ground.

The shunt regulator **450** includes additional circuitry to regulate the voltage of the node **480**. In particular, the shunt regulator **450** includes a current source **458** that supplies current that flows through the source-to-drain path of a PMOSFET **460**. The source terminal of the PMOSFET **460** is coupled to the supply rail **68**. The gate-to-source voltage of the PMOSFET **460** is coupled in parallel with a resistor **462**. Thus, the bias current that is established by the current source **458** establishes a given current flow through the resistor **462**. The drain-to-source path of an NMOSFET **466** is serially coupled to receive the current through the resistor **462**. The drain terminal of the NMOSFET **466** is coupled to the gate terminal of the PMOSFET **460**, and the source terminal of the NMOSFET **466** is coupled to the output node **480**. The gate terminal of the NMOSFET **466** is coupled to the drain terminal of the PMOSFET **460**. Due to this arrangement, the NMOSFET **466** provides the current to the supply node **480** as needed to regulate the voltage of the node **480**.

Referring to FIG. 7, in accordance with some embodiments of the invention, the frequency synthesizer **10** may be part of a wireless system **800**. As examples, the wireless system **800** may be a portable wireless device, such as a cellular telephone, a personal digital assistant (PDA), or a portable computer, as just a few examples. It is noted that the wireless system **800** may be a more non-portable device, such as a desktop computer. Thus, many variations are possible and are within the scope of the appended claims. The wireless system **800** includes, for example, a transceiver that may include a low noise amplifier (LNA) **804** that receives an RF signal from an antenna **802**, a radio **810**, analog-to-digital converters (ADCs) **814**, a baseband processor **816** and digital-to-analog converters (DACs) **820**, and the frequency synthesizer **10**.

All of the components of the wireless system **800** described above may be fabricated on a single die and may be part of the same semiconductor package, in accordance with some embodiments of the invention. In other embodiments of the invention, the above-described components may be fabricated on separate dies of a single semiconductor package. In yet other embodiments of the invention, the above-described components may be part of separate semiconductor packages. Thus, many variations are possible and are within the scope of the appended claims.

The LNA **804** receives an RF signal from an antenna **802** and provides an amplified version of the incoming RF signal to a radio **810**. The radio **810** receives one or more mixing signals from the frequency synthesizer **10** for purposes of translating the incoming RF signal to a lower baseband frequency. The resultant signal is provided to the ADCs **814** that produce baseband signals in response thereto. The baseband processor **816** may, for example, de-modulate the signals provided by the ADC **814** and provide the resultant de-modulated signals to the DACs **820**. The DACs **820**, in turn, may provide audio signals for speakers **824** and **828**.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art, having the benefit of this disclosure, will appreciate numerous modifications and variations therefrom. It is

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intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

What is claimed is:

1. A shaping circuit comprising:
a chain of serially coupled inverters having an input terminal to receive a sinusoidal signal and an output terminal, the chain of serially coupled inverters comprising a first inverter closer to the input terminal than the other inverters and a second inverter of said other inverters connected to an output terminal of the first inverter, wherein the sizes of said other inverters progressively increase from the second inverter to the output terminal of the chain, and the size of the first inverter is larger than the second inverter.
2. The shaping circuit of claim 1, wherein the first inverter and said other inverters are complementary metal oxide semiconductor inverters.
3. The shaping circuit of claim 1, wherein the chain of serially coupled inverters convert the sinusoidal signal into a clock signal, and the first inverter substantially establishes an edge speed of the clock signal.

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4. A method comprising:
providing a chain of serially coupled inverters to convert a sinusoidal signal received at an input terminal of the chain into a clock signal provided at an output terminal of the chain;
coupling a first inverter of the chain closer to the input terminal than the other inverters;
connecting a second inverter of said other inverters to an output terminal of the first inverter, the size of the first inverter being larger than the size of the second inverter; and
progressively increasing the sizes of said other inverters from an output terminal of the first inverter to the output terminal of the chain.
5. The method of claim 4, wherein the first inverter and said other inverters are complementary metal oxide semiconductor inverters.
6. The method of claim 4, wherein the first inverter substantially establishes an edge speed of the clock signal.

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